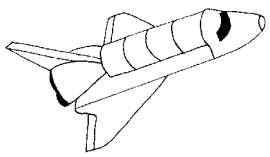
Volume 9, No. 1 Winter, 1996

WISCONSIN FAST PLANTS notes BOTTLE BIOLOGY WISCONSIN



Teachers and Students Investigating Plants in Space

In May of 1995, the presidents of the United States and Ukraine issued a joint statement on cooperation in space, directing the National Aeronautics and Space Administration (NASA) and the National Space Agency of Ukraine (NSAU) to cooperate on a joint Space Shuttle mission (STS-87). The project was named the "Collaborative Ukrainian Experiment," or CUE. The flight is scheduled for October, 1997.

The science payload for STS-87 will be several plant biology experiments in an environmentally controlled Plant Growth Facility, among which is one involving experiments on pollination, fertilization and embryogenesis of a special dwarf Fast Plants stock known as "AstroPlants."

Dr. Mary Musgrave at Louisiana State University and Dr. Antonina Popova of the National Academy of Sciences of Ukraine will be addressing the question of what developmental events during plant reproduction fail in the microgravity environment. The larger question is how will plants grow and function in microgravity considering that they have evolved and existed in an environment of Earth's gravity?

Classroom Involvement

The education portion of the mission is called "TSIPS" (Teachers and Students Investigating Plants in Space). In concert with the Ukrainian payload specialist's performing the experimental procedures aboard STS-87, teachers and students throughout the two countries have the opportunity to conduct "real time" investigations focusing on similar questions to those addressed in the Space Shuttle using the same rapid-cycling AstroPlants.

An instructional materials manual for the high school and advanced middle school levels has been written to include investigations on germination, orientation, growth and development, pollination, fertilization and embryogeny. The materials emphasize skills of observing, questioning, hypothesizing, experimenting, analyzing and communicating, and are aligned with the National Science Standards.

The plans for experimental classroom equipment have been designed using low cost, readily available materials and will simulate the Shuttle's Plant Growth Chamber (PGC) and its environment. Students will grow their AstroPlants as usual under 24 hour/day fluorescent light, in 1g gravity, but in the simulated PGC.

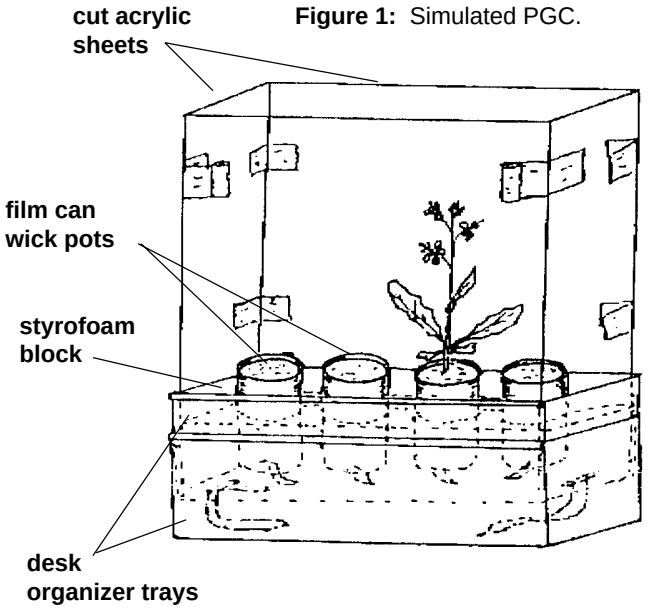


Figure 1: Simulated PGC.

Lead teachers have already been chosen in both the U.S. (sponsored by NASA and the Wisconsin Fast Plants Program) and in Ukraine (sponsored by the Ukrainian Junior Academy of Sciences). During the spring and summer of 1997 these lead teachers, together with educators from NASA centers, will train other teachers in the CUE-TSIPS experiments. It is expected that their students will generate large amounts of experimental data that can serve as ground control information to be compared with information gathered from the flight experiments. Communication over the Internet will permit data sharing among classrooms and between the United States and Ukraine. The CUE-TSIPS activities will be assessed for their value in student and teacher learning.

Get Involved!

The instructional materials will be available from NASA. Interested teachers can contact the Fast Plants Program, ***beginning mid-March, 1997,*** for details about the manual and teacher workshop sites and dates. Interested teachers and students can also visit the Fast Plants World Wide Web site at http://fastplants.cals.wisc.edu. For information about a training workshop in Madison in the summer of 1997, see the back page of this issue of *Notes*.

Lead Teacher Training in Kiev, Ukraine

In October, 1996, Dr. Paul Williams, director of the Wisconsin Fast Plants Program, together with Peter Chetirkin and Tom Dreschel of Dynamac Corporation, Kennedy Space Center, presented a hands-on workshop in Kiev, Ukraine, for the CUE-TSIPS lead teachers in the Ukrainian Junior Academy of Sciences.

In the picture at left, Ukrainian science teachers, Natalia Kuzhelyuk and Roman Osipenko construct their experimental Plant Growth Chambers (PGCs).

In the background at the right is Dr. Volodimir Nazarenko, Ukrainian coordinator for the CUE-TSIPS project.

TSIPS Activity: Tumbling in Space

Concepts

Rooted in the ground, plants, unlike most animals, are unable to move or relocate themselves in their environment from their fixed position. They are, however, capable of orienting themselves so as to optimize their capacity to access the environmental components essential to their life. The way in which plants orient themselves to light and gravity is called *tropism*.

Plants use guidance systems which sense and respond to gravity (*gravitropism*) ensuring that roots anchor plants and access water and that shoots emerge into the light. Plants then use light to activate energy-capturing photosynthesis. Light also guides the development of leaf expansion (*photomorphogenesis*), stem bending and elongation (*phototropism*), and pigment (chlorophyll and anthocyanin) production.

Questions

- How does a seedling orient itself?
- How does a plant grow up?
- Why does the shoot grow up and the root down?

Background

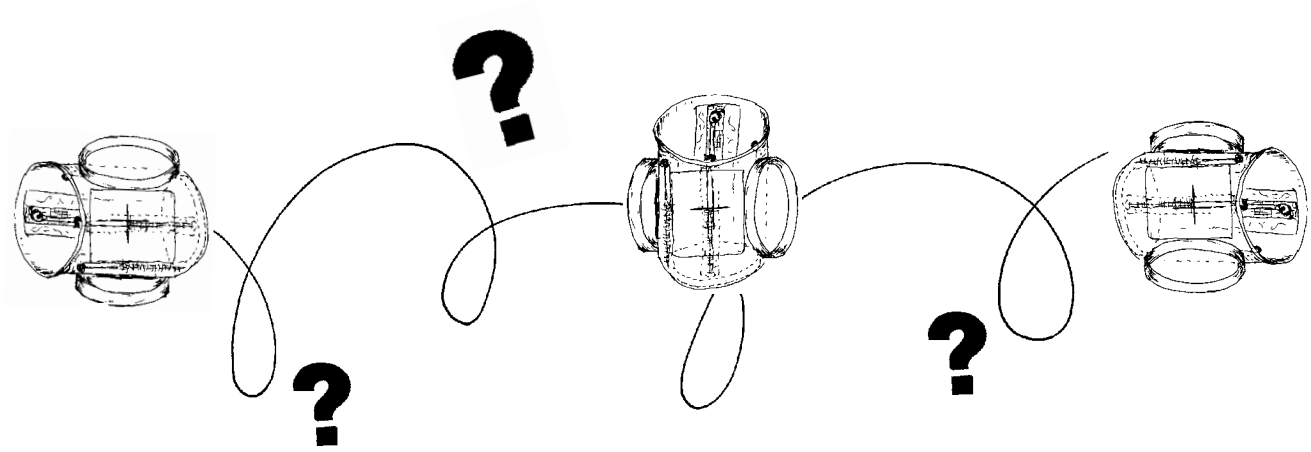
Plants, like many other organisms including humans, use both gravity and light for orientation and guidance in their environments.

Roots exhibit positive gravitropism and shoots negative gravitropism. Whereas shoots are also positively phototropic, bend or grow toward a gradient source of light, plants like humans rely heavily on gravity for orientation. We are especially aware of the verticality of our orientation as we lean forward or lift a heavy object.

Horizontality is mostly afforded us by light through sight. Our awareness of a horizon provides us with an essential sense of where we are in space. Just shut your eyes for a few moments and you come to realize how important horizontality is to your orientation. The effects of the horizon on your sensory stability can be best experienced in movie experiences of stunt aircraft flights or on a roller coaster where the horizon is constantly changing. In the absence of sight, gravity and other sensory systems (sound, smell, touch) provide compensation in our orientation.

Since plants in the absence of light rely on gravity for orientation, an interesting question for plant biologists is, in the environment of microgravity in the absence of light, are there other ways that a plant can become oriented? This and other questions will investigated in future missions.

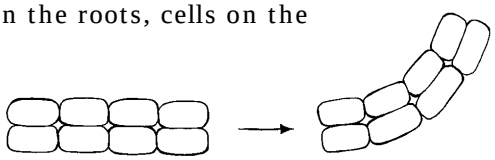
In the microgravity of the orbiting Space Shuttle, humans and plants are deprived of the force of the Earth's gravity on which to orient. Astronauts and cosmonauts orient visually on the many structures within the orbiter. If they need more absolute orientation for the orbiter, they can make sightings on the Earth, sun or stars.



In space, plants must orient using light. Just how plants orient themselves to the light is still under intensive studies by plant physiologists. Perhaps the best place to do such studies on phototropism is in the Space Shuttle, where the confounding influence of gravity as a guiding force is minimized.

Seedlings of various plants including rapid-cycling *Brassica rapa* and AstroPlants are excellent model organisms with which to investigate the influence of light on tropic bending. Visible light includes a spectral range from 400 nm to about 750 nanometers wavelength ranging from ultraviolet through blue, green, yellow, orange to red and infrared. Plants use different colored molecules to capture various wavelengths and use that energy for different functions, including photosynthesis, phototropism (bending), and photomorphogenesis (enlarging and expanding).

The gravitropic response in plants is thought to be largely controlled by a group of growth promoting hormones called *auxins*, and by inhibitors of auxins. When a plant is turned on its side, auxins stimulate elongation in the cells on the lower side of the shoot, causing it to bend up (against gravity), but in the roots, cells on the upper side elongate causing the roots to grow down (with gravity).



In phototropism, an unequal distribution of auxins and inhibitors on the side of the plant away from the light stimulates cell enlargement on the "dark" side of the plant and results in the plant bending toward the light. Much has yet to be learned about the mechanism of tropism in plants.

Introduction to the Activity

This activity utilizes the "film can gravitropism chamber" in just one of many experiments that can be designed to answer a large number of questions that students may ask relating to the question: How do plants 'know' which way to grow?

Let's make an assumption that on Earth, in the absence of light, plants sense and respond (orient) to the gravitational force of 1g (*unit gravity*).

Question: How responsive is the germinating AstroPlant seedling to Earth's gravity?

Sample Hypothesis: The AstroPlant seedling hypocotyl will respond rapidly and continuously, exhibiting negative gravitropism at least over a 72 hour period.

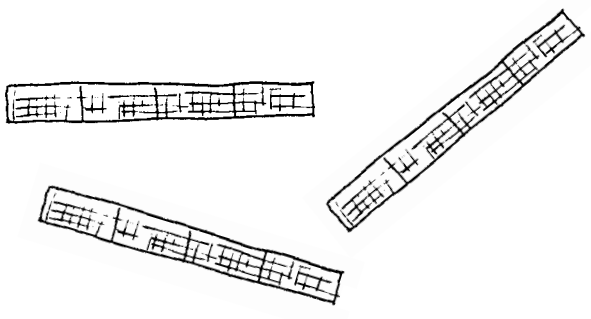
Design: Seeds are germinated in the dark over several days and are observed and measured for their directions of growth. At specified intervals of time, orientation is altered progressively by 90˚ of rotation through 360˚. At each orientation growth response is predicted, observed and recorded.

Materials (for a group of 3-4 students)

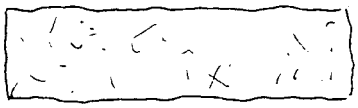
- 35 mm opaque film can with lid
- 2 extra film can lids
- clear double stick tape
- white masking or lab tape, 2 cm wide
- 1 floral foam disc, 28 mm diameter, 2-4 mm thick
- 4 grid strips, made of 0.5 x 4 cm of clear plastic transparency sheet with 1 mm grid photocopied onto it
- 4 wick strips, 1 cm x 4.5 cm strips of soft paper toweling
- 4 AstroPlants seeds, Fast Plants seeds, turnip, lettuce or alfalfa seeds
- water bottle
- forceps to handle seed
- ultrafine permanent black marker
- hi-low thermometer

Preparation

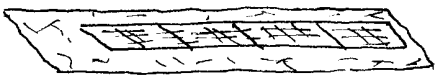
- *Making grid strips:*
  - Copy millimeter square graph paper onto an overhead transparency sheet.
  - Cut the sheet along the lines to make strips with the dimensions 0.5 cm x 4 cm.
  - Grid strips can be reused after rinsing, soaking for 20 minutes in a 20% bleach solution, then rinsing again and drying on paper toweling.



- *Making wick strips:*
  - Fold a square sheet of kitchen paper toweling to form an eight layered rectangle (Scott® towels work well).
  - With scissors, trim end and folds to make a rectangle with the dimensions 4.5 cm x 10 to 12 cm.
  - Cut wick strips from the rectangle by cutting 1 cm x 4.5 cm strips.

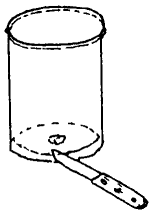


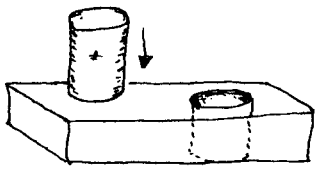
- *Making germination strips:*
  - When you are ready to complete your chamber hold a grid strip and wick strip together and moisten the wick strip so the wick strip adheres to the grid strip to produce the germination strip.



  - The wet germination strip will adhere to the inner wall of a film can. Place the grid strip toward the inner wall.
  - The seed will adhere to the wet wick strip .

- *Making floral foam discs:*
  - Prepare discs by cutting foam cylinders with a Fuji® brand "film can foam cylinder cutter" created by cutting off the bottom of a Fuji® film can and beveling the outside edge with a sharp blade or knife. Cylinders will have a diameter of 28 mm.





  - Cut foam cylinders by carefully pressing the cylinder cutter completely through a dry floral foam block.
  - With a flat knife slice discs of foam 2-4 mm thick from the cylinders.

Procedure

1. Construct your film can gravitropism chamber:
   - On each extra film can lid place a 3 cm strip of double stick tape and then attach the lids to the outside wall of the film can so that each lid is opposite the other.
   - Mark the film can using an ultrafine tipped permanent marking pen to draw arrows on the film can lid and one of the mounted lids as in Figure 2 to indicate FRONT.

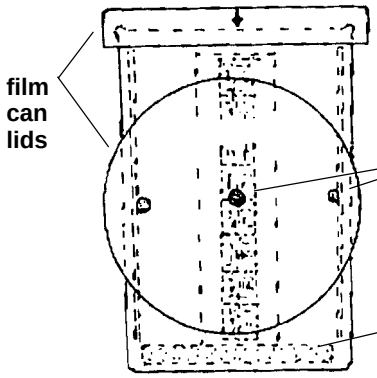


Figure 2: Front view of film can gravitropism chamber.

   - With the front facing you, stick a white label on the right side of the chamber and draw a compass on the label, marked with angles of 0˚/360˚, 90˚, 180˚ and 270˚, corresponding to north, south, east and west (Figure 3).

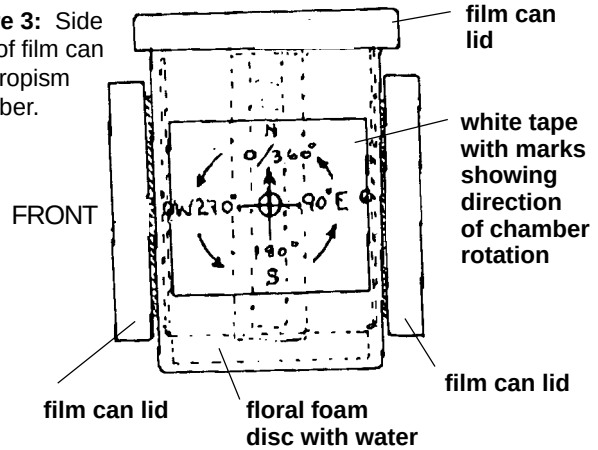


Figure 3: Side view of film can gravitropism chamber.

   - As indicated in Figure 3, draw in arrows indicating a counterclockwise direction of rotation.

2. Place the floral foam disc in the bottom of the film can.

3. With a water bottle, add enough water to saturate the floral foam and just a little more free water in the bottom.

4. While holding one wick strip with a grid strip aligned on top of it between your thumb and forefinger, or between the tips of a forceps, dip the end of the wick strip into the bottom of the can, touching the water until it wicks up some of the free water.

   - As the wick strip becomes moist through capillary action, the grid strip will adhere to it through the adhesive forces of the water. Together the wick and grid strips make a *germination strip*.

5. Align the pair vertically against the film can inner wall with the grid strip next to the wall and the wick strip wrapping over it and adhering to the film can wall as illustrated.

   - You may tilt the film can to encourage the free water to ascend the wick strip and speed the adhesion of the wick to the wall.

6. Align the germination strip with the front orientation of the chamber. At this stage you may let the strip extend above the rim of the film can chamber.

7. Repeat the procedure with the other germination strips, aligning them to create four strips opposite each other aligned at 90 degree angles, as illustrated.

8. Now remove one strip pair from the chamber and with your finger or using seed forceps to pick up one rapid-cycling brassica seed, place it about 2 cm down the strip. The seed will adhere to the wet paper towel.

9. Replace the strip with seed to its original position in the can, but this time push the germination strip down so that the bottom of the wick strip connects with the wet floral foam disc and the top of the strip is below the rim of the film can chamber. *It is critical that the top of the germination strip is below the rim, or when the chamber is closed, the moisture from inside will "wick" out of the can.*

10. Repeat steps 8-10 until all 4 seeds are on the four wick strips in the chamber.

11. Make a final check on the amount of water in the bottom of the chamber.

    - If there is excess free water, gently tip the chamber and let the extra water drip out, making sure not to wash off the seeds.

12. Gently place the film can lid on, sealing the chamber. Be sure that the arrow on the lid is aligned with the arrow on the front lid.

    - As indicated in Figure 4, each strip has a numbered position, 1-4: 1 is front, 3 is back, 2 is left and 4 is right.

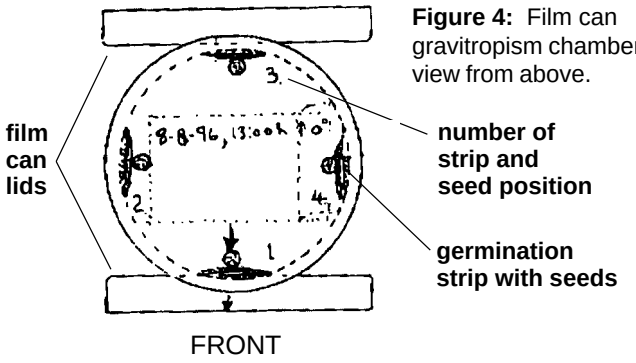


Figure 4: Film can gravitropism chamber, view from above.

13. Put a white tape label on the top lid of the film can with the following information recorded: your name, the date and time (on a 24 hour clock, e.g., 18:00 hours), the symbol "0˚" indicating the initial orientation (upright) of the chamber at the specified date and time.

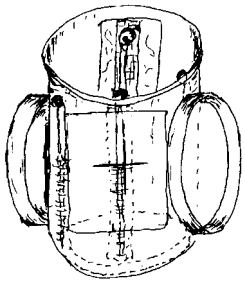
    - *Germination in the absence of light has begun at 0 time.*

14. Place your chamber in the upright, 0/360 degrees position, where a relatively uniform temperature between 22˚C and 30˚C can be maintained. Under your light bank is ideal, or take your chamber home with you.

15. Be prepared to record the range and average daily temperature during your experiment.

16. Be prepared to observe your seedlings every 6 to 12 hours, noting the elongation of the hypocotyls.

- When you observe your seed and seedlings, keep the lid open only for as long as necessary to observe them.



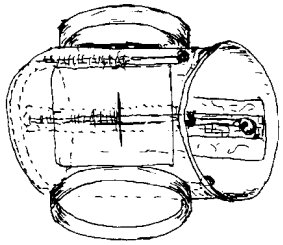
- If a seedling has fallen off of its wick strip, it may be placed back gently, picking it up with a forceps.

- If a seedling's root is growing off of the wick strip, it can be gently pressed to the wick where its root hairs will attach firmly.

- If it looks like more water is needed, add a few drops to the foam disc.

17. Sometime between 24 and 48 hours, depending on the temperature, the hypocotyls of your seedlings will be between 1 and 2 cm long. Make a drawing of the vertical seedling on each strip (1-4) in the appropriate boxes of the Gravitropism Data Sheet (0 rotation angle boxes).

18. At this time rotate your chamber 90 degrees. As you rotate your chamber, think about the possible outcome of reorienting your four seedlings.



- What will the seedling on each strip look like after 3 to 12 hours? Make a drawing in the 90 degree rotation angle boxes of what you predict you will see for each seedling (1-4) when you open the chamber in 3 to 12 hours.

19. Record the date and time of your first 90 degree rotation on the Gravitropism Data Sheet, and each rotation thereafter.

20. After 3 to 12 hours (3-6 is best), observe your chamber. On the Data Sheet next to your predicted sketch, make a quick accurate sketch of how the plant on each strip appears.

- Then rotate the chamber another 90 degrees to the 180 degree position, make a predictive drawing and after 3 to 12 hours, repeat the cycle of observation, drawing and rotation.

21. Continue rotating, observing and drawing until you have completed 360 degrees of rotation. Would you like to try to keep it going? Try it!

22. When you have finished carefully remove each strip with its seedling attached and make a final drawing of each on the Gravitropism data sheet.

- Stretch out each seedling, straightening it out, and accurately record the length of the hypocotyl from the hypocotyl from the cotyledon to the root hypocotyl junction above where the root hairs first appear. On the Gravitropism Data Sheet, record the length of the hypocotyl in millimeters.

Additional Questions

- What is the average length of the hypocotyls in your chamber after X hours of germinating in the dark (you fill in the time)?
- What was the average temperature during your experiment?
- How long do you think it is possible for a brassica hypocotyl to grow in the dark?
- Is there a limit to how long it would grow? If there is, what is it?
- When it is elongating, how is the hypocotyl actually growing longer? By what mechanism?
- Is there a limit to how much bending a hypocotyl can undergo?
- Do you have evidence to accept or reject the original hypothesis?
- How strong is your evidence?

References

Darwin, C. 1880. *The Power of Movement in Plants*. J. Murray Publishing (London).

Hart, J.W. 1990. *Plant Tropisms and Other Movements*. Unwin Hyman Publishing (London).

Salisbury, F.B. 1993. Gravitropism: Changing Ideas. In Offprints from Horticultural Reviews, Volume 15, pp. 233-278.

Wisconsin Fast Plants. 1995. Plants Know the Way to Grow. WFP (Madison, WI).

Gravitropism Data Sheet

Student Name 1 _____
Student Name 2 _____
Student Name 3 _____
Student Name 4 _____

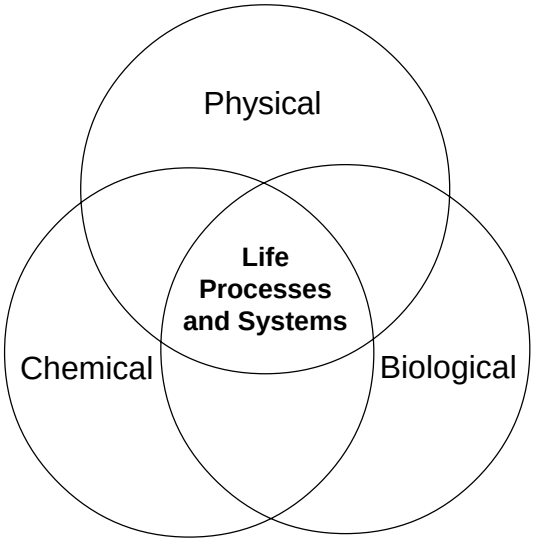
Environment
Temperature Range: _____
Average Daily Temperature of Growing Environment: _____

Germination Strip Position Number

Date	**Time (24 hr clock)**	**Hours**	**Hours from Last Rotation**	**Rotation Angle**	**1**		**2**		**3**		**4**	
					predicted	observed	predicted	observed	predicted	observed	predicted	observed
		0	0	0								
				90								
				180								
				270								
				360								
length of hypocotyl after _____ hours					_____ mm		_____ mm		_____ mm		_____ mm	

Tech Section: Understanding the Environment

Three broad categories of environmental components interact to influence all life: 1) physical, 2) biological and 3) chemical. Understanding the many environmental factors and how they interact with each other to influence life is essential for good investigative science and is the key to successful experimentation with AstroPlants. In space life science investigations such as the CUE, scientists and engineers have worked together to develop machinery that will create an environment to support normal plant growth within the hostile external environment of space.



Some environmental factors influence plant growth more than others. If one or more factors is reduced or increased such that normal functioning is disrupted, that factor is said to be *limiting*. Usually when a factor that can be quantified becomes limiting, its effects can be observed and also quantified.

The Physical Environment

Light

Appropriate lighting is perhaps the most critical component of the plant's growing environment. Plants use energy from various regions of the visible spectrum to perform a number of functions essential to their growth and reproduction. Some seeds require red light to activate germination. Blue light is important for regulating elongation of stems and in guiding the direction of plant growth. Red and blue are the primary energy levels used for photosynthesis, whereas red and far red are important in the regulation of leaf expansion and certain pigment production systems.

Irradiance of greater than 200 $\mu Em^{-2}s^{-1}$ is **ideal** for Fast Plants. Less than 100 $\mu Em^{-2}s^{-1}$ is **inadequate**. Between 200 and 100 $\mu Em^{-2}s^{-1}$ is **adequate** light.

As with other electromagnetic forces and gravity, the inverse square relationship applies to light. That is, if the distance between the source of light and the receiving surface doubles, the intensity of the irradiance diminishes by a factor of four.

Fluorescent lamps used for Fast Plants emit a mix of photons in the visible range that appear as white with more or less warm (red) or cool (blue) in the mix. The quantity of photons reaching a surface is known as *irradiance* or *photon flux density* and is measured in micromoles (µM) or microEinsteins (µE) of photon flux per square meter per second.

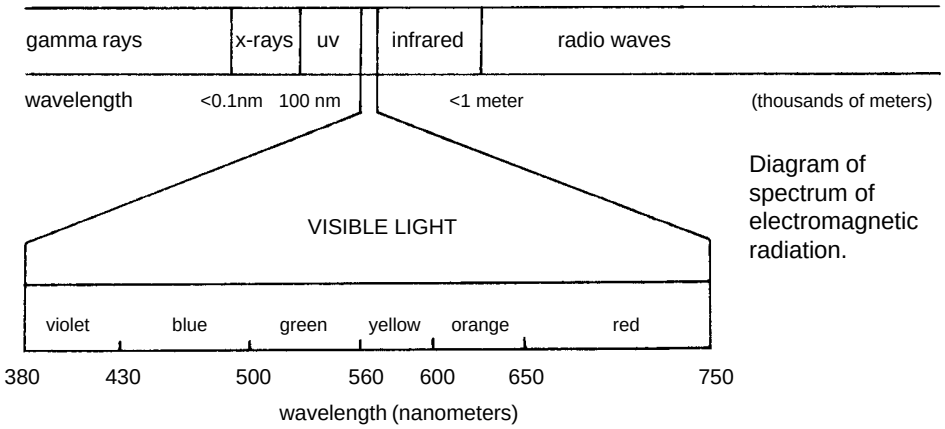
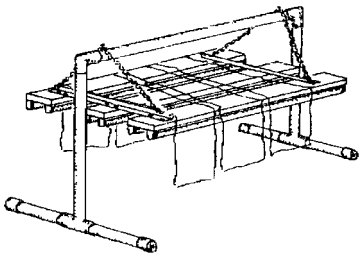
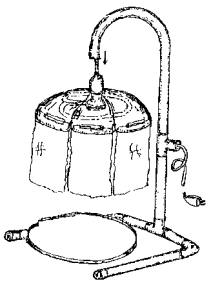


Diagram of spectrum of electromagnetic radiation.

If you are using the standard four-foot Fast Plants light bank, you can use either eight 40 watt cool white or six of the newer 32 watt high efficiency bulbs which will require different fixtures than the 40 watt bulbs. Six 32 watt Sylvania Octron® 4100K FO32/741 lamps spaced within two feet will produce ideal lighting for AstroPlants.





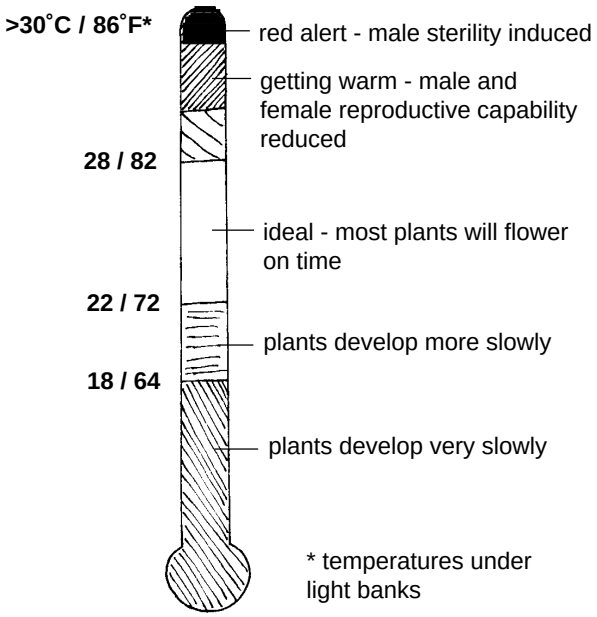
Fluorescent 'circle' energy saver lamps can be suspended above and will adequately irradiate the plants growing within a circle of 30 cm diameter (12 inches). The Wisconsin Fast Plants Program has had good growth under 30 watt Lights of America or 39 watt General Electric circular or folded circular bulbs.

Reflectors and reflective "curtains" made from aluminum foil or reflective mylar (available from fabric or stationery stores) greatly increases the irradiance reaching the plants, particularly those around the edges of the lamps. Aluminum foil curtains (15 cm x 25 cm) taped on the lamp fixture to hang down to about the soil level will contribute to uniform lighting across the plants.

Tip: Keeping the plants under constant 24 hour light will produce the most satisfactory results. Be sure to make arrangements (with custodians, etc.) so light banks are not turned off at any time.

Temperature

The temperature of the plants' growing environment will have an important influence on the growth of your plants. Temperatures that are too high or too low can affect the timing of developmental events such as seedling emergence and flowering. Optimal temperature is between 22˚C and 28˚C (72˚F-82˚F).

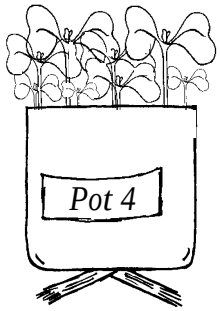


Temperatures can be monitored under each bank using hi-low thermometers available from hardware, garden, or electronic stores. Note fluctuations in the room temperature and variation in temperature among light banks. Remember that the temperature in the plant canopy under lights may be 1-3˚C warmer than room temperature.

NSTA 1997

At the NSTA National Convention in New Orleans (April 3-5, 1997):

- **attend a hands-on workshop** presented by the Fast Plants staff on CUE-TSIPS;
- **drop in at the NASA booth** where the Fast Plants staff will highlight the CUE mission and CUE-TSIPS activities.
- **stop by the Fast Plants booth** to see the living graph of "The Population Explosion," including the introduction of a plant pathogen into the population vs. density system featured in the Fall, 1995, issue of WFP/BB *Notes*.

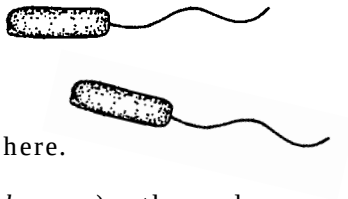


The Biological Environment

Types of Organisms

There can be many types of organisms associated with the environment of your plants, from algae to insects. These organisms may reside together in various *symbiotic* relationships, from mutually beneficial relations to *parasitic* (one partner benefits) and even *pathogenic* (one partner harms the other). Some symbioses may be strictly neutral. Controlling undesirable organisms in the plant's environment requires continued attention. Possible residents include:

- various soil *microflora* (bacteria, fungi) and *microfauna* (nematodes, worms, insect larvae) colonize the root zone of influence or rhizosphere.



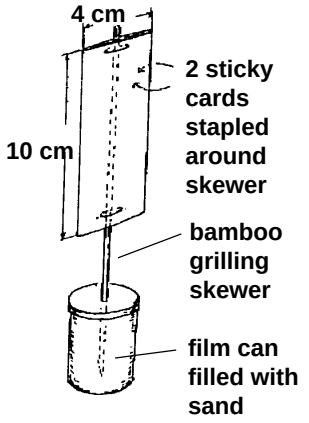
- plant eating (*phytophagous*) arthropods can be found on stems, leaves and flowers. These include mites, thrips, aphids, leaf-eating beetles and lepidopteran larvae (moths and butterflies).
- the larvae of fungus-eating (*mycophagous*) flies may exist in large numbers, emerging from the root medium and water mat as small black gnats.
- algal populations thrive on the moist root media, capillary wicking material and in the nutrient reservoirs. Most common are blue-green algae (*cyanobacteria*) on root media and mat surfaces and green algae in reservoirs.

Controlling Undesirable Organisms

Fungi and Bacteria: Fungi and bacteria rarely attack the above-ground parts of plants as long as the relative humidity is less than 95% and there is good air flow. The best control for fungi and bacteria is sanitation. Be sure to use pathogen-free root media - most commercially available peatlite mixtures are sanitized and pathogen-free. Keep the root medium well aerated and drained by not packing it down in the growing containers. After growing, it is important to rinse, then soak all pots, reservoirs, capillary mats and wicks for at least 30 minutes in a 10% chlorine bleach solution. Root media should not be reused.

Algae: The most common residents with Fast Plants are algae. Most do not affect plant growth, but can become unsightly and occasionally will build up in reservoirs and wicking to consume nutrients and retard water flow. Covering exposed mat surfaces with pieces of black plastic from trash bags inhibits algal growth. Algae growth on soil surfaces can also be suppressed by adding copper sulfate ($CuSO_4 \cdot 5H_2O$) to the nutrient solution at a final concentration in the reservoir of between 50 and 100 ppm (mg/liter).

Insect Pests: The continuously illuminated plants can be attractive to many insects, especially at night. Daily surveillance and removal is good practice. The use of sticky yellow pest control cards work well to trap incoming insects and flies emerging from the soil. Ortho® Sticky White Fly traps from garden stores can be cut and stapled to bamboo grilling skewers and mounted in film cans filled with sand which can be placed among the plants. These are very effective for white flies, aphids, fungus gnats and thrips.



If colonies of aphids, white flies or thrips appear or evidence of larval feeding (holes chewed in leaves or flowers), plants may be sprayed with insecticidal soap or other safe chemical control agent. Surveillance and careful removal by hand is the best control practice.

The Chemical Environment

Atmosphere

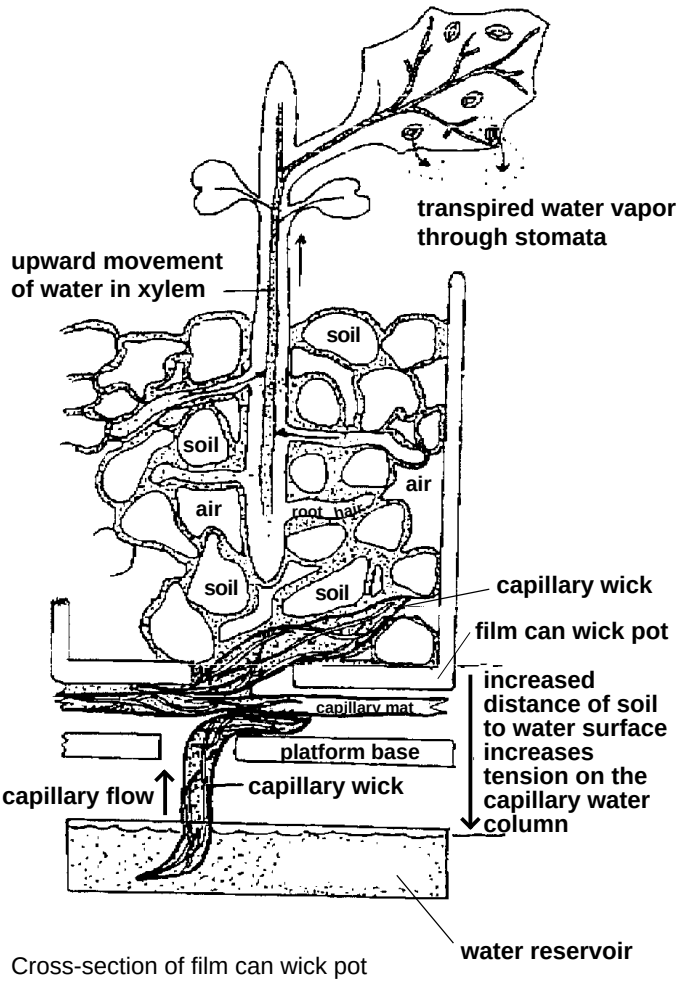
Ambient air contains nitrogen (78%), oxygen (21%), hydrogen and helium (<1%). Carbon dioxide in air is approximately 350 ppm and is the primary source of carbon incorporated into organic molecules via photosynthesis. In closed systems, where humans and other organisms are respiring, CO_2 levels may build up to toxic levels. On the Space Shuttle orbiter, CO_2 levels are carefully monitored and excess removed from the atmosphere by chemically trapping it. In space, plants have the potential role in extracting CO_2 from the air and converting it into edible biomass.

Water

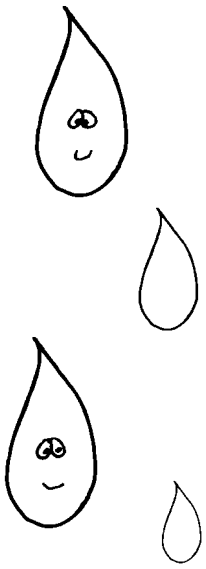
Water functions in many ways in plants, serving as the primary solvent supporting life's metabolic processes, generating turgor for cell enlargement and growth, maintaining ionic balance and providing cooling via transpiration. As well, water is the source of hydrogen reducing power when it is split by light energy in photosynthesis. Water enters the plant primarily through the root epidermal and hair cells, traveling through intercellular space and cortical cells to the xylem tissue where it is distributed throughout the plant.

Within the root zone water is found adhering to soil particles and is continuously interconnected as a film created through the cohesive forces of the water molecules. The adhesive forces of attraction of water molecules for the surfaces of soil particles and plant root cells pull the water into the minute channels within the soil and plant tissues via the process of *capillarity*.

Capillary wicking material (e.g., WaterMat®) is used to pull water from a reservoir to a soilless root medium which has strong capillary properties. In plants there is an unbroken continuity of water from the soil into and throughout the plants (see figure at right). Through this water course, the plant also gains access to inorganic nutrients. On Earth gravity acts as a vertical counter force creating tension on the capillary water column.



Cross-section of film can wick pot in CUE-TSIPS growing system.

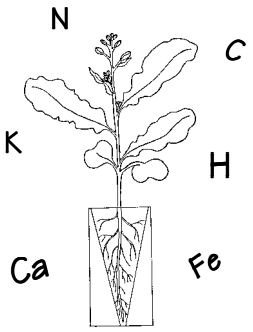


Atmospheric Humidity

The relative humidity of your classroom can affect the rate of transpiration and water uptake by your plants. Under low relative humidity there can be rapid water uptake from the reservoirs. When reservoirs run dry, capillarity is broken and plants will desiccate and die. When plants begin to wilt, it is an indication that transpiration is exceeding water uptake. In some climates this occurs when there has been a rapid drop in atmospheric relative humidity. In these cases plants usually adjust by reducing transpiration and regaining their turgor.

If wilting persists, check the water reservoir levels and examine the capillary wicks and matting to be sure they have not dried out and broken the capillary connection between roots and reservoir.

If the atmospheric relative humidity is very high (>95% RH) in flowering Fast Plants, the mature anthers may fail to open (*dehisce*) to release their pollen. This occurs when plants are grown in closed containers in which the relative humidity builds up. Indehiscence of anthers can be remedied by circulating air over the plants with a fan. Mature anthers will then usually dehisce within a few minutes.



Inorganic nutrients

In addition to the elements carbon, oxygen and hydrogen which make up the main structure of organic compounds in plants, 13 other elements are required to support the range of metabolic processes that constitute life.

Six elements – nitrogen, potassium, calcium, phosphorus, magnesium and sulfur – are known as *macronutrients* because they are required in relatively greater quantities than the seven *micronutrients* – iron, chlorine, copper, manganese, zinc, molybdenum and boron.

Student Project Highlight:
Rocket Shoots Fast Plants Seeds through the Aurora

The rocket with its precious cargo returned to Earth in snowy Alaska.

Fast Plants seeds from Lori Gillam's class at Stellar Secondary School in Anchorage, Alaska, rocketed through the high energy particles of the *aurora borealis* in February of 1996. With the cooperation of Neal Brown, an assistant professor at the Geophysical Institute at the University of Alaska-Fairbanks and Andrew Christensen, Director of the Space and Environment Technology Center at the Aerospace Corporation in California, the seeds from Ms. Gillam's class were secured among the weather instruments on a rocket that was set off at the Poker Flat Research Range. Teacher, students and scientists wanted to investigate how exposure to the aurora's electrical currents might affect plant growth rates.

Working in cooperative groups the students subsequently conducted original investigations on the radiation exposed Brassica seeds. They found out that the "answers" were really more questions! However, in germinating and growing the experimental plants, they did observe what appeared to be some abnormalities, the most frequent being plants with three cotyledons and five flower petals. As Lori reported, only with more research could there be confirmation that the abnormalities were due to aurora radiation.

Aurora is the Roman Goddess of the dawn.

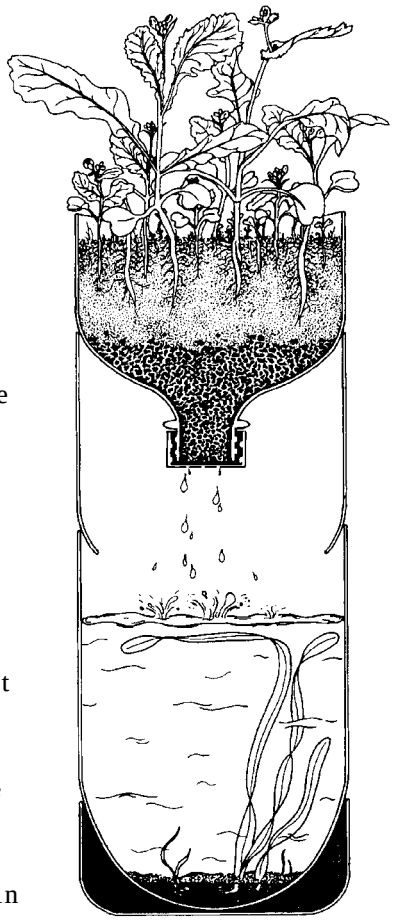
Borealis is the Greek God personifying the north wind.

Aurora borealis is Latin for northern dawn (northern lights).

From the students – "We learned:
- patience.
- the text doesn't always have the answer.
- science isn't always clean and neat.
- science doesn't end when the class is over.
- mistakes happen.
- answers are rare."

Is There A Pollution Solution?

The Effect of Salt on Fast Plants



Salt (mainly sodium chloride, NaCl) is introduced into the environment in many different ways and can cause a wide variety of problems. In the northern United States, salt is frequently used to melt ice on *roads*. Most of this salt ends up in roadside soils.

Overhead *irrigation* can cause the buildup of salts on farm fields. This is due to the evaporation of the irrigation water and corresponding deposition of salt which was originally dissolved in this water.

In coastal areas, extensive well pumping of ground water aquifers causes the *infiltration* of salts from the oceans into these aquifers and related soils.

Through the use of *TerrAqua columns* and Fast Plants, it is possible to model some of the effects of salt on the environment. Fast Plants are a good choice for vegetation in the terrestrial system because they will respond quickly to the presence of salt. Their rapid life cycle also makes it easy to observe the effects of salt at different stages of a plant's development.

Fast Plants grow well in a TerrAqua column when planted in a "field" of 20 to 30 plants. You may want to plant more than this number and then thin three or four days after sowing. Also, don't forget to fertilize your Fast Plants: 50 ml of a one tablespoon/gallon of 20-20-20 Peters solution at four, seven, and 14 days works well for a two-liter TerrAqua bottle.

Algae are a good addition to the aquatic component of a column because they are also very sensitive to salt. A film can's worth of pond water added to the water reservoir at the beginning of an experiment will serve as an inoculum of a diverse collection of algae. Don't worry if you cannot see anything at first. Algae grow quickly, especially if there is a source of nutrients such as "runoff" from the terrestrial component of the TerrAqua column.

If you know ahead of time that you will be needing algae in the winter, and you live in a cold winter-freezing environment, collect pond water in the fall and put it in an aquarium with some sort of water movement system. However, beware of tropical fish bubblers: they can add too much oxygen to the water and kill your aquatic plants.

You may also want to occasionally add fertilizer, perhaps one-half cup of 1X 20-20-20 Peters or equivalent, once a month. When building your aquarium, you may want to add an inch or so of pond bottom to act as an additional source of nutrients, especially micronutrients, and as an additional source of algae.

To model contamination, use a one percent (weight/volume) salt solution as a starting concentration. It is important to use pure salt. Regular table salt contains both iodine and 'flowing agents' which might effect your results. Lab grade NaCl works well, and you can also use pickling or kosher salt.

Because the size of salt crystals can vary considerably, it is best to weigh out the salt you will be using. Dissolving 20 grams of salt in 2.0

The following ditty can be sung to the tune of "Oh my darling, Clementine."

"Evaporation,
Condensation,
Precipitation on the ground,
Percolation and then runoff,
And it goes on round and round."

Contributed by Joyce Roderick, Thomas Jefferson Middle School, in Madera, CA.

liters of water in a two-liter soda bottle works well. A simple hand-hanging postal scale works well for weighing the salt; a film can clipped to the scale can hold the salt while weighing. You may want to use distilled water for your solution to avoid any potential effects of treated tap water.

To simulate salt contamination from above, use a watering bottle made from a soda bottle. "Rain" onto the Fast Plants and soil around 100 ml of the salt solution on days three, six, and nine. Adding salt to the soil before or at planting will significantly reduce germination rates. Direct application of salt onto the leaves of Fast Plants has a damaging effect.

Salt infiltration can be modeled in a TerrAqua column by adding salt to the aquatic system below and connecting it to the terrestrial system above with a capillary wick such as Pellon® or Watermat®. A good place to start with these experiments is to use the same one percent salt solution mentioned above as the starting aquatic solution in the column. It may take time for the salt to move into the soil above, so have some patience and keep your eye out for initially subtle changes in the growth of plants in the terrestrial system.

In any experiment, it is important to keep a control. This is easily accomplished by running a parallel column which is treated with pure water every time salt solutions are added to the experimental columns. If you are running parallel salt columns, such as one with salt from above and the other from below, add equal volumes of salt or water to each column for each treatment.

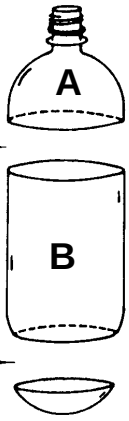
Keep close observations on as many aspects of the columns as possible. All sorts of surprises can pop up! One which you may find interesting is the differential loss of water from the aquatic system of the column under different salt treatments. This is likely caused by salt related physiological stress and the resulting reduced transpiration rates.

Cut Bottles

1st bottle

Cut to leave 1-2" of the cylinder on the shoulder.

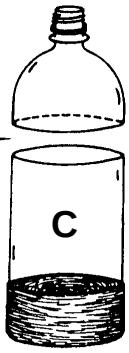
Cut to leave 3/4" of the hip on the cylinder.



2nd bottle

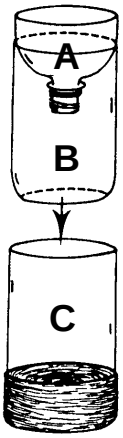
Cut across top of cylinder leaving straight sides.

Leave base attached.



Combine Bottles

Invert Part A and insert into part B.

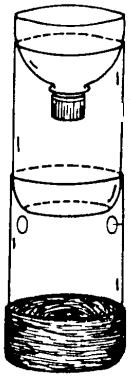


Add Finishing Touches

Punch small holes in cap.

Screw cap onto bottle.

Cut or melt into the top sides of the lower bottle.



CUE-TSIPS Workshop

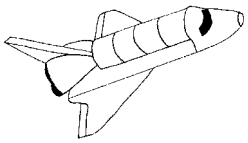
University of Wisconsin-Madison
July 9-11, 1997

Calling all Fast Plants-experienced high school teachers who want to participate the Shuttle mission activities in October, 1997!

The Fast Plants Program offers a three day training workshop to prepare you and your students to participate in CUE-TSIPS activities.

In this issue:

Addressing the life cycle in space, germination and orientation, the workshop will be rich in math, statistics and technology that align with the National Science Standards.



Presenter: Paul Williams
One credit, graduate level, UW-Madison. No stipends are available.

For more information, contact Ruth Owens, Wisconsin Teacher Enhancement Program in Biology, by phone at at 608-262-1006 or by fax at 608-262-2976.

General inquiries should be directed to:

Coe Williams, Program Manager, Wisconsin Fast Plants
University of Wisconsin-Madison, Dept. of Plant Pathology
1630 Linden Drive, Madison, WI 53706
tel: 1-800-462-7417 or 608-263-2634 fax: 608-263-2626 email: fastplants@calshp.cals.wisc.edu
WWW: http://fastplants.cals.wisc.edu

Christie M. Roden and Daniel W. Lauffer, Editors.

Funding for this project has been provided by a grant from the National Science Foundation and the National Aeronautics and Space Administration.

Wisconsin Fast Plants
University of Wisconsin-Madison
Dept. of Plant Pathology
1630 Linden Drive
Madison, WI 53706

Nonprofit Organization
U.S. Postage
PAID
Madison, Wisconsin
Permit No. 658